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# Distribution, utilization structure and potential of biomass resources in rural China: With special references of crop residues

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## Abstract

As the largest developing country in the world, China is urgently in short of energy and natural resources. However, biological resources such as crop residues are burnt in the field, which cause serious environmental pollution. Still it is not clear how much storage and potential of these huge crop residues are in China. This paper firstly reported the distribution, utilization structure and potential of crop biomass and provided the tangible information of crop residues in rural China through careful collecting and recalculating data. From 1995 to 2005, China produces some 630 million tons of crop residues per year, 50% of which comes from east and central south of China. The amount of crop residues is 1.3 times of the total yield of crops, 2 times of the total fodder of grassland, which covers 41% of China's territory. Crop residues of corn, wheat and rice amounted to 239, 137 and 116 million tons, respectively, accounting for nearly 80% of the total crop residues. Unfortunately, the utilizing structure is seriously improper for such abundant biomass resources. Although 23% of the crop residues are used for forage, 4% for industry materials and 0.5% for biogas, the large parts are used with lower efficiency or wasted, with 37% being directly combusted by farmers, 15% lost during collection and the rest 20.5% discarded or directly burnt in the field. Reasonable adjustment of the utilizing pattern and popularization of the recycling agriculture are

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essential out-ways for residues, with the development of the forage industry being the breakthrough point. We suggested that utilizing the abandoned 20.5% of the total residues for forage and combining agriculture and stock raising can greatly improve the farm system and cut down fertilizer pollution. Through the development of forage industries, the use efficiency of crop residues could be largely enhanced. Commercializing and popularizing technologies of biomass gasification and liquefaction might be substitute solutions of China's energy shortage.


*Keywords:* Rural China; Biomass resources; Crop residues; Biomass energy; Comprehensive utilization

**Contents**



## 1. Introduction

Biomass resources are residues after crop or wood harvest in agriculture and forest industries, which could be transformed into energy or forage. Firewood, crop residues, animal manure, energy plants and municipal solid waste (MSW) are the common biomass resources. Currently, biomass energy accounts for about 14% of primary energy consumption all over the world, justly inferior to petroleum, coal and natural gas. It is recognized as the main part of future regenerative energy [1]. Biomass resources are the production of current photosynthesis, with carbon coming from the atmosphere rather than from the deep earth. Therefore the utilization of biomass resources will not cause excessive $CO_2$ emission. Further and sufficient exploitation of biomass resources is hopeful for future energy security, global carbon balance and sustainable development of agriculture.

The expansion of fossil fuel exploration and combustion has caused many problems such as energy crisis and global warming since the Industrial Revolution. A number of

researchers have focused on the potential of renewable energy [2–5], expecting to solve the energy crisis. Some others studied the disturbance of greenhouse gases emission to climate change or the buffering effects of biomass resources [6,7]. Up to now, great progresses have been achieved from systematic analysis of global energy structure [8,9] for accurate evaluation of the distribution and utilization potential of global biomass resources. Some predicted that 15% of the global primary energy supply would come from biomass energy in 2050, with crop residues reaching to 21 $GJ\,ha^{-1}\,yr^{-1}$ [10]. Still some pointed out that by 2050 the contribution of biomass to global energy would fluctuate from 100 to 400 $EJ\,yr^{-1}$ [11]. However, this statement is challenged by other researchers, for example, Hoogwijk [12] argued that the bioenergy supply would have a big range (33–1135 $EJ\,yr^{-1}$), among which energy plants would take the most important place (0–988 $EJ\,yr^{-1}$). For all those evaluations, nevertheless, biomass resources were constantly treated as biomass energy, the comprehensive utilization of biomass resource being rarely thought.

From the practical point of view, projects such as biomass electricity generating or biomass liquid fuels producing have already been ranked in national energy strategy in most developed countries [13]. Conversely, direct combustion of firewood and crop residues is still the main energy gaining manner in the majority of developing countries, especially in Asian and Pacific areas, with severe pollutions always occurring despite of energy wasting [14,15]. Therefore, efficient and clean utilization of biomass resources is considered as a requisite approach in improving the ecological environment in developing countries [16,17].

Occupying 20% of the world population, China has a population over 1.3 billion, with 70% of its population engaging in farm or pastoral careers [18]. Although China has achieved success in feeding its huge population, the farmland area is so small that the contradiction between human being and farmland is acute. China has 0.13 billion hectare farmland, which is only 8.6% of the world [19]. Under the immense pressure of the huge population, farmland in China could hardly fulfill the demand of the rapid economic growth by increasing only the crop yield, if the crop residues were neglected. Crop residues are not only quite convenient energy sources for farmers; but also the best forages for animals (cattle and sheep). For example, crop residues related materials are feeding some 67% of China's livestock. However, the utilization efficiency can be higher if the crop residues industry technologies are applied, since still many livestock now are fed directly with dry crop residues. Therefore, more and more Chinese researchers put crop residues as the most important aspect of biomass resources in China [20]. Even some believe crop residues are the prospect of biomass energy transformation [21–24].

Although recent studies paid much attention to the detailed distribution and utilization of biomass resources in China [25–27], most of data were composed of only one year, with nearly all the data being displayed in energy units to calculate the potential of biomass resources. So we find out that some of the data calculated by the former researchers are hardly useful in real practice, especially from the ecological and environmental points of view. Further, the estimated amounts of the tremendous crop residues in rural China varied in a large scale from 620 to 940 million tons from different literatures, which might bring confusions for decision-makers and for those who want to study the distribution of crop residues in China. Meanwhile, the macro-level policy-makers who lead the utilizing directions of biomass resources in China urgently need to know the recent biomass resource situations. To meet both the theoretical and practical requirements, this paper firstly reports the newest information of distribution and utilization of crop residues in

rural China by carefully filtrating and calculating statistical data. In this paper, we have also analyzed the development potential and pointed out directions of crop residues, to provide scientific basis for high efficiency and reasonable utilization of biomass resources in China.

## 2. Methods

### 2.1. Information sources

The original information in this study mainly came from: (1) Yearbooks, including "China Statistical Yearbook" from 1996 to 2005 [18,28], "China Agriculture Yearbook 2004" [29], "Rural energy yearbook (2003) of China" [30], "Almanac of China Paper Industry 2005" [31], etc.; (2) Annual reports, such as "Annual report of China National Bureau of Statistics", "Investigation and assessment of current ecological environment in China (2003)" [32], "Annual report of China Paper Industry 2000–2005" [33], etc.; (3) Network information, including International Energy Agency (IEA) Energy Statistics Databases [34], Chinese Academy of Sciences Energy Research Institute Scientific Database [35], Food and Agriculture Organization of the United Nations (FAO) Statistical Databases [36], etc. All the referred social information were from the official web portal of Chinese Governments or from the related enterprises; (4) Literatures, there was little data from literatures which are principally used for comparison.

### 2.2. Data recalculation

All the results about crop residues distribution in this paper were based on recalculation of original data. Data composed of crop yields from 1995 to 2004 were further classified into crop species and provinces. Then the crop yields were transformed into crop residue values and recalculated, with the mean universal values being gained. The methods in calculating the quantities of crop residue utilization were improved after Zeng et al. [27], however, we collected much huge database from a series of years. Through recalculation, more believable proportions of each kind of utilization types have been achieved, despite of some fluctuations among years. The potentials in crop residues processing were showed in forms of both energy (J) and criterion coal (Mtce) and other units, basing on their current quantities, practical utilizing possibility and the authoritative transform coefficients. Besides complicated data collection and filtration work, there was only basic statistical analysis. We used the Microsoft Excel and Sigma Plot (Ver. 6.1, SPSS, Chicago, IL, USA) to perform the calculations and draw figures.

## 3. Results

### 3.1. Gross amount of crop residues

The residue/crop product coefficients were from the research report "Assessment of biomass resources availability in China" [37], which represented the general situations of transforming crop-residue product in China (Table 1). In order to obtain the accurate distribution of crop residues, 10-year data from 1995 to 2004 were selected and analyzed [18,28].

Table 1
Residue/crop product coefficients and average yield of residue by crop categories (1995–2004) in China

| Crops | Yield of crops ($10^6$ ton) | Coefficient [37] | Yield of residues ($10^6$ ton) | Proportion (%) |
|---|---|---|---|---|
| Corn | 119.2±10.3 | 2 | 238.5±20.5 | 38.0 |
| Wheat | 102.2±12.0 | 1.336 | 136.5±15.9 | 21.8 |
| Rice | 185.8±13.0 | 0.623 | 115.8±8.1 | 18.5 |
| Oil-bearing crops | 26.1±3.5 | 2 | 52.3±7.0 | 8.3 |
| Beans | 20.0±1.7 | 1.5 | 30.0±2.5 | 4.8 |
| Tubers | 35.2±1.7 | 0.5 | 17.6±0.8 | 2.8 |
| Cotton | 4.8±0.7 | 3 | 14.3±2.0 | 2.3 |
| Other crops | 11.5±3.9 | 1 | 11.5±3.9 | 1.8 |
| Sugar crops | 89.6±8.9 | 0.1 | 9.0±0.9 | 1.4 |
| Fiber crops | 0.8±0.2 | 2.5 | 1.9±0.5 | 0.3 |
| Total | 595.2±24.3 | | 627.3±27.4 | 100 |

Data are presented as means±SD, $n = 10$.

Crop residues resources in China are mainly from corn, wheat, rice, cotton and other crops. However, crop residue is not a statistical index but rather a complex unit, therefore we estimated the amount of crop residues by transforming the corresponding crop products that could be found in statistical databases. With the increasing population and continual reduction of total farmland area and farmland area per capita (Fig. 1A), China still got 484 million tons of crop product in 2005, 22% of the world crop product [36]. As a result, the crop residues (in dry weight) had increased following the stable ascent of crop product from 1970s to 1990s, peaking 660 million tons in 1998. Even though, there were some fluctuations in crop product at the beginning of this century (Fig. 1B).

The average yield of crop residues in China was estimated at 630 million tons in the last decade, 78% of which were from corn, wheat and rice (Table 1). Corn, as a higher photosynthetic $C_4$ species, was noted to have both the highest seed and stalk yields among all kinds of cereals. However, corn stalk that is twice as weight as seed has not been paid much attention. Since most of the cornstalks were burnt in the field by farmers simply for the convenience of growing winter wheat.

We also calculated the crop residues increase rate since 1970s, and found the average rate in the last two decades was about 1.2%. This is a stable index because that there is little possibility for China to enlarge its farmland area, so the yield of crop residues would reach about 700 million tons in the future 10 years. Considering agriculture is restricted by regional and climatic traits, the major crop production regions and proportions would not change drastically. Therefore, the data provided in this paper would be representative and applicable.

### 3.2. Distribution of crop residues

China's plain regions are the main sources of crop residues, with four districts being involved, i.e., east, central south, northeast and central China. There are seven provinces in east China where crop residues are plentiful with the maximum being Shandong, six provinces in central south China with Henan the maximum, three provinces in north east China (Jilin, Heilongjiang and Liaoning provinces) and six provinces in north China with

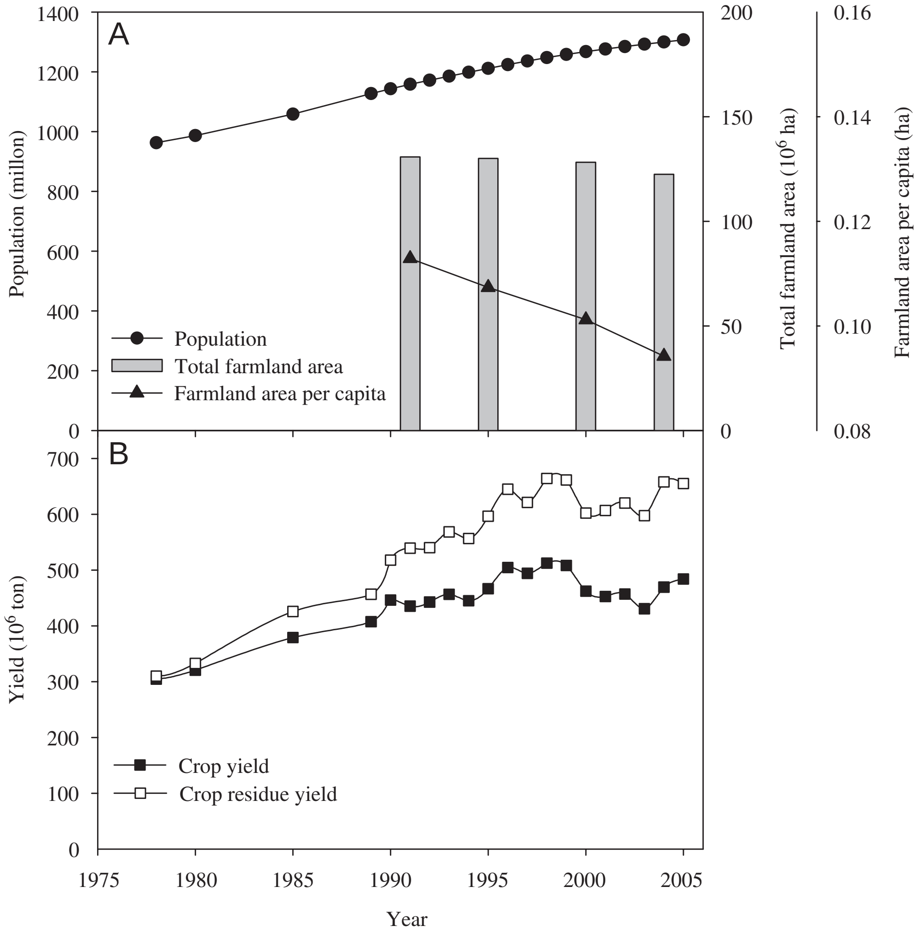


Fig. 1. Dynamics of farmland area and population during the period of 1978–2005 (A), 1978–2005 yield of crop and yield of residues (B) in China.

Hebei the maximum (Fig. 2). As for the distribution pattern, 50% of the total crop residues concentrated in only two districts (east and central south China), in where the highest population density and severest resources crisis exist.

The detailed compositions of crop residues in China were noted as follows. Corn, took up 38%, mainly from north east, east and north provinces; wheat took up 22%, mainly from central south, east and north China; rice took up 19%, mainly from central south, east and south west provinces. Others like beans, tubers and oil-bearing plants were only 4.8%, 2.8% and 8.3%, respectively. However, most of these small parts of crop residues were often discarded with little usage purposes.

## 3.3. Current utilization

Nowadays, after the part returning to fields or collection lost, crop residues from corn, wheat and rice are principally used as green manure, forage, industry material and fuel.

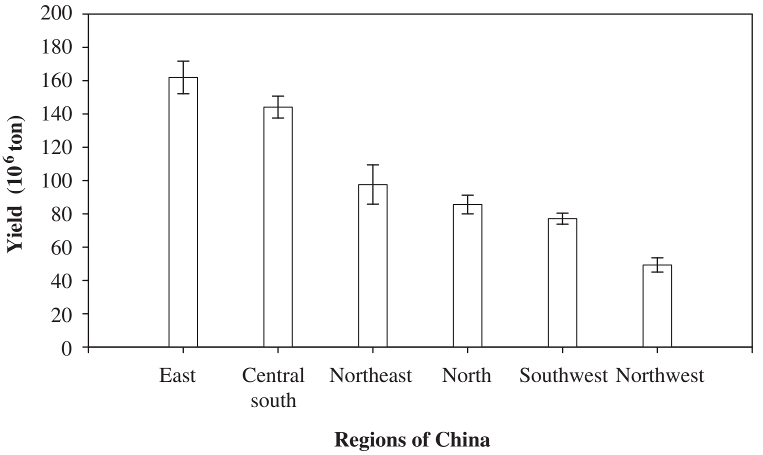


Fig. 2. The 1995–2004 average yield of residues by regions of China. For each mean ($\pm$SD), $n = 10$.

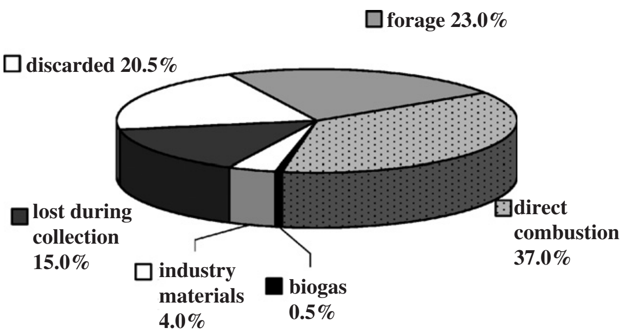


Fig. 3. Current utilization situations of crop residues in rural China.

Low efficient direct combustion as fuels is still the primary way of usage for the purpose such as cooking or heating in rural China. Through careful calculation, we have found that 15% of the total crop residues had been lost during collection then return to the fields, 23% used for forage, 4% for industry materials, 37.5% left for bioenergy (37% direct combustion and 0.5% biogas), and the rest 20.5% discarded directly through burning in the field, which caused serious environmental pollution (Fig. 3).

### 3.3.1. Collection lost and returns to the fields

Return to the fields was the oldest indigenous utilization of crop residues as energy in rural China, which could balance the nutrient cycling. Such traditional agricultural method has been widely studied [38,39]. Nowadays, direct returning the stalks to the fields is still practiced for its facility, through either turning the crop stubble over into the soil or spilling the crop residues into pieces by special machines. Besides those direct returns, indirect returns to the fields were also popular in China, including organic fertilizers after fermentation, manure digested by livestock and ashes. However, clean techniques with

higher efficiency for high temperature fertilization and anaerobic digestion have not fully developed, therefore the applications of efficient indirect returns are still limited.

Because of the small scale and dispersed agriculture harvest, and the fact that people in China are used to return the crop residues to fields, the proportion of crop residues for collecting lost and returning to the fields was quite large. Many literatures have predicted that such a value reached to about 15% [26,37,40]. Our results here confirm the proportion. We believe such proportion (about 90 million tons) of crop residue utilization will be relatively stable in several future decades, if no particular technologies are invented. If only direct exploited ways are considered (e.g., except the reused part like biogas silt), with more application of chemical fertilizers and more mechanization of farming, the conventional way of returning crop residues to fields would gradually decline.

### 3.3.2. Direct combustion

Averagely 250 million tons of crop residues per year were directly combusted, occupying 37% of the total yield of crop residues. In the past several decades, 30–45% of the household energy came from direct crop residues combustion in rural China. Recently, along with the increase of living standard, farmers have greatly changed their energy structures: commercial energy sources like coal, liquefied petroleum gas (LPG) and natural gas were consumed by more and more farm families. Therefore, despite the stable consumption of crop residues, its contribution to the energy use had fallen from 45% in 1991 to 29% in 2003 (Fig. 4A and B). Meanwhile, the proportion of crop residues used for direct combustion to the total crop residues fluctuated with crop output. Although such a proportion varied a lot in the beginning of 1990s and reduced a little in recent years, 37% was an average value during 1996–2003 which could be a more accurate estimation (Fig. 4B). As we can see, with the changes of rural energy structure, such a 37% direct combustion of crop residues in stoves would decrease either.

Nevertheless, energy efficiency of the traditional stoves burning crop residues was merely 10%; while that of the Kang (a kind of heating beds by burning firewood underground) in rural northern China was even lower (7%). Thus, direct combustion caused a great deal of fuel waste and serious indoors air pollution, especially the indoors respiratory aerosols, CO and $SO_2$, etc. [41,42]. To overcome such shortages, since 1980s, the Chinese government has spread the fuel-saving stoves, with 20–30% efficiency being increased. Some 190 million families (86% of the total rural families) were benefited from the fuel-saving stoves, ovens and Kangs by 2004. Provided that 1–1.5 ton crop residues or firewood could be saved per year by fuel-saving stove, 76 million tons standard coal would be saved, indicating 410 million tons $CO_2$ would be cut down in rural China [43]. However, we could not expect extending fuel-saving stoves to solve all the comprehensive crop residues utilization problems, as the ultimate solution is to reduce the direct combustion, rather than reform it.

### 3.3.3. Forage

The demand in China for poultry, eggs and milk has grown rapidly these years, which greatly stimulates the development of breeding industry as well as the fodder enterprise. Unfortunately, 70% of present stock raising industry is pork in China, which is grain-consumptive type, with the grains consumed for fodder being above 30% of the total crop yield [44]. Therefore, the stock raising industry in China cannot be satisfactory at all. One of the two main fodders in China is high quality forage from grains. Although such forage

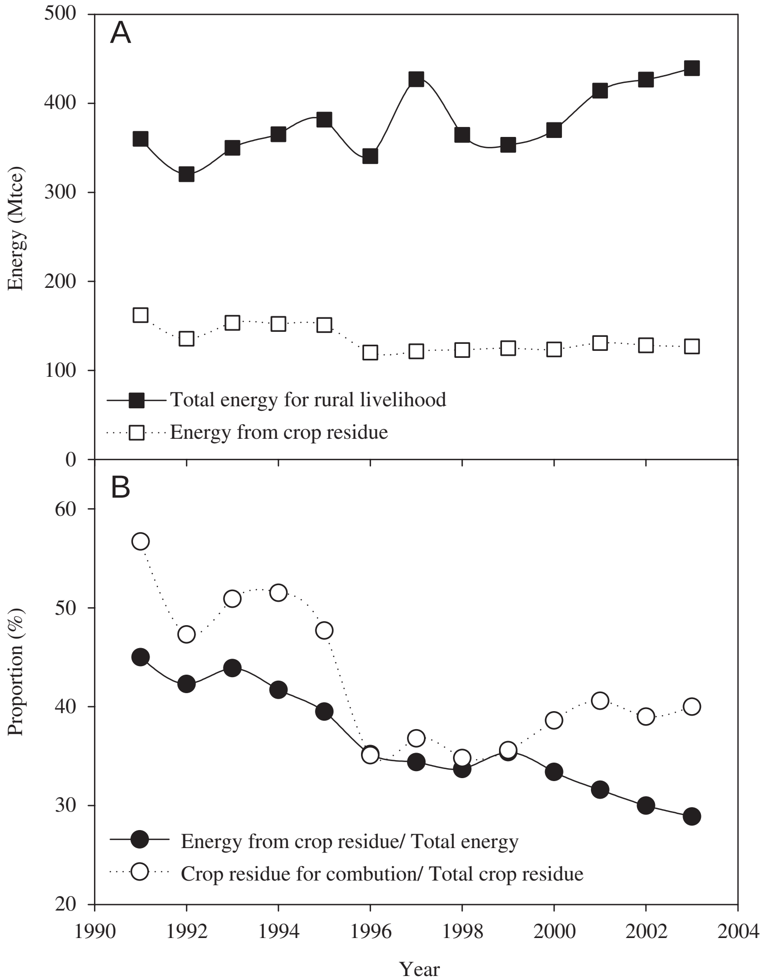


Fig. 4. Direct combustion of crop residues as energy source for livelihood in rural China.

possesses better breeding effect, its high price makes it only adopt by some large factories, holding the majority of scattered raisers back. On the one hand, China is pressingly short of good and cheap fodders; on the other hand, grain-source fodder companies are closing down for their difficult sales. Furthermore, if grain-source fodder were advocated widely, it would be a threat to food security. The other fodder is the low quality forage from coarse fodder (like crop residues or vegetables etc.), which has big market especially for family animal raisers. This is the main way for scattered raisers for the cheap price and broad sources, but the long raising time and small scale leads low benefits.

Cattle are the most common outlets for crop residues when they are used as forage in rural China. The need for meat or domestic animals in China has been increasing year by year, with 140 million cattle at the end of 2004 [18]. We recalculated the data published by Du et al. [44] and found that the number of livestock raised in China's traditional pasturing area together with the semi-pasturing area is only 29%, 16% and 4%,

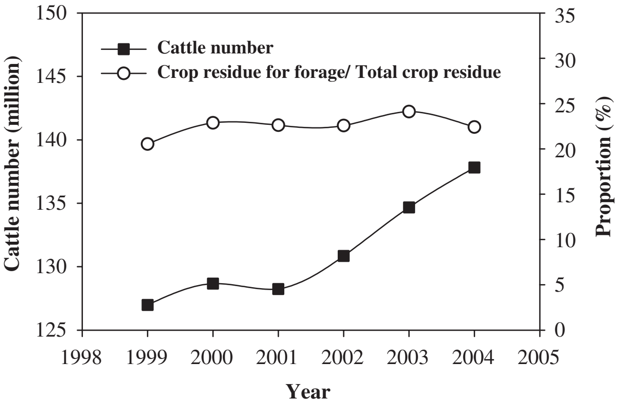


Fig. 5. Crop residues as forage in China.

respectively, of the entire output of sheep, cattle and pigs. That is to say, 84% cattle are from China's farming regions feeding on crop residues. According to the results reported by the Chinese Agriculture Development Academy Institute, about 3.49 kg crop residues are consumed per cattle per day, or 1274 kg per year [45]. Based on this calculation we could figure out the amount of crop residues used as forage, which was 147 million tons in the year of 2004. Since the cattle number has added rapidly since 2000, the crop residues yield also increased so that we may conclude the proportion of crop residues for forage keeps around 23% (Fig. 5).

*3.3.4. Industry materials*

As for industrial purposes, crop residues were mainly utilized for papermaking, with a very small part for other purposes such as chemical materials, stalk arts and crafts. So here we only consider the quantity for papermaking. With the rapid improvement of technology and the strict controlling of water pollution, the raw materials for papermaking now are mainly from the recycled waste papers, lumbers, fibrous crops especially hemp. Therefore papermaking materials from crop residues composed of a small part, with only corn stalk and rice husks being the basic stuffs.

Owing to short of forest resources and increase of the paper pulp consumption, the import of paper pulp and waste paper has been enhanced rapidly. Consequently, the proportion from paper pulp and waste paper boosted; with the non-pulp materials like crop residues declining obviously, from 32% in 2000 to 25% in 2005 [31] (Fig. 6B). According to the recent data, 1 ton pulp needed 2.25–2.5 ton crop residues. Taking the improvement of papermaking techniques and efficiency into account, we adopted 2.25 ton per ton pulp as average value. Recently, the total product of paper and paperboard in China increased gradually, so the crop residues used for papermaking was also increasing, peaking 30 million tons in 2003. But compared to the enormous general product, the content of crop residues used for papermaking was only 4% (Fig. 6A and B).

*3.3.5. Biogas*

Biogas is burnable gases emitted by mixed crop residues, human and animal manure and organic wastes under anaerobic conditions, which are widely used for household

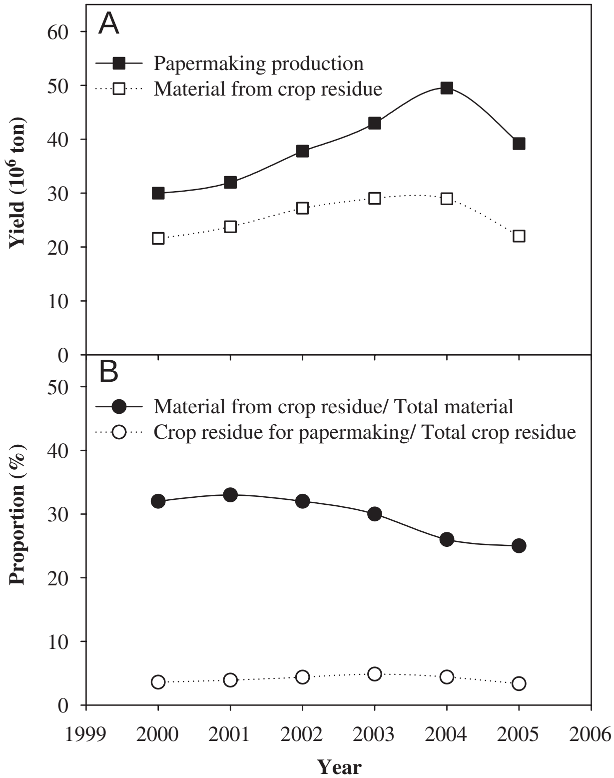


Fig. 6. Crop residues as papermaking material in China.

cooking or illumination. China is leading the developing countries in spreading and applying biogas technique [43]. The major component from the biogas is $CH_4$ whose heat value is $2.0 \times 10^4\,kJ\,m^{-3}$. There is another kind of biogas emitted by crop residues only, which is composed of mixed $N_2$ and CO, with heat value being only $0.5 \times 10^4\,kJ\,m^{-3}$. We therefore neglected this part because it is barely applied for its lower heat value. Because crop residues have higher value of carbon/nitrogen ratio, pre-silage and ferment with manure are necessary to regulate carbon/nitrogen ratio in order to gain higher gas yield. Normally the weight of crop residues is requested to below $\frac{1}{3}$ of the raw materials for biogas generation. Considering the lost parts during the piling process, we used $\frac{1}{3}$ as the reasonable ratio of crop residues composing of the biogas raw materials. The biogas emission ratio ranged from 0.3 to $0.5\,m^3\,kg^{-1}$ in rural China [46], thus the amount of crop residues for biogas could be estimated. For example, $5.6 \times 10^9\,m^3$ biogas was consumed by about 15 million families in 2004, equaling to 4 million tons standard coal. Although more than 3.7 million tons of crop residues in the future will be used for the purpose of biogas production, the ratio is still the lowest, only 0.4% of the total yield of crop residues in China. Even there is an up trend for biogas uses with the encouragement of regenerable resources by Chinese government. However, biogas cannot govern the utilization of crop residues resources.

## 4. Discussion

### *4.1. Livestock raising industries with crop residues could release food crisis in China*

Although the total grain yield in China had a peak record of 512 million tons in the year of 1998, a 5-year continuous yield decrease (to 431 million tons in 2003) alerts China's food crisis again [47]. It is predicted that China's population would reach 1.6 billion in 2030, which means the grain demand would increase to 640 million tons if the consumption rate (400 kg $yr^{-1}$ per capita) remains unchanged. Such severe situation clearly indicates that the gap between future grain need and present grain yield would reach to 160 million tons.

China has attached intense importance to grain yield for thousands of years. However, farmers' enthusiasm in growing crop is challenged by the low price of grain and the high cost of planting. In fact, farmers had taken away only less than half of the photosynthetic product (i.e., grain), direct burning crop residues in the field wasting most of biomass resource and causing environment pollutions. If the wasted part were fully utilized as forage, China would gain a great deal of meat and milk product. Higher protein food instead of merely grain would not only release the food crisis, but also advance the physical quality of China's huge population. Theoretically, energy and nutrients in crop residues nearly equal to that of grains; the key point is how to transform them through raising livestock.

Based on the present distribution and utilization conditions, we concluded that developing crop residue forage would be the most potential, practical and valuable way of comprehensive utilization of crop residues. To realize this, the breakthrough point is industrialization of crop residues forage, which can stimulate the intact industry chain including crop residues collection, machining, and forage distribution, animal breeding and selling.

Although China boasts to have 330 million hectares grassland, the productivity is somewhat lower, with about 300 million tons dry fodder yield per year [44]. Contrast sharply to this figure, area of farmland is only 130 million hectares, however, each year, farmland alone can produce 480 million tons of grain and another 630 million tons of residues, with the productivity being 3.7 times of the grassland production (while its land area only 40% of the grassland). Overgrazing in west China such as Inner Mongolia and Xinjiang deteriorates the originally frail environment [48], merely getting some livestock product in return. If the 20.5% unused and 37% direct combustion parts of crop residues were processed into forage, more than 300 million tons forage could be expected, equaling to the total forage yield of the entire grassland. Unfortunately, direct combustion wastes the huge biomass of the primary product, equivalent to the primary product of 250 million hectares grassland. In another word, the wasted crop residues resources give us a chance of adjusting the substance and energy balance, from grassland ecosystem to agroecosystem.

Actually now 84% cattle and 71% sheep are from rural China [44], however, low efficiency of directly using crop residues as feed causes resource waste. Therefore the new techniques of crop residues forage are extraordinarily needed. Crop residues from soybean, corn, wheat and bagasse are preferable for their high nutrients. Corn stalks in northern China are especially important for their abundance and feasibility in use. Although agglomerate and granule crop residues forage are very practical for their high density, easy transport or storage, and could be applied for many kinds of crop residues, such technology is still expensive for farmers. Fortunately, now we have found the solution for

solving such shortages, e.g., turning the dry stalks into "fresh" forages through microbe ferment technology [49,50].

### 4.2. Crop residues are the main sources for biomass energy

In 2003, China went over Japan to the second place in the consumption of oil energy. Although the quantities and proportions of high efficient energies like oil, natural gases have increased these years, the energy structure of China is still less reasonable against the world average [51]. More than 65% of the primary energy comes from coal, which causes serious air pollution especially acid rain. In rural area, since 55% of the energy consumption is from direct biomass burning (about 30% is crop residues and 25% is firewood), leading to environmental pollutions [41]. Although crop residues are still the most important energy source, the increase of commercial energy in countries decreases the demand of crop residues largely. So farmers begin to fire or discard the surplus stalks, bringing a great waste of biomass resources. As the bio-energy utilization concerned, we considered the following aspects should be stressed.

(1) *Crop residues gasification*: Biomass like crop residues can be transformed into combustible gases (CO and $H_2$) through pyrogenation reaction, and then supplied to users through tubing network. Developed countries, especially western European countries and the US, have already industrially applied such biomass gasification technique to many fields as heating, generating electricity and cooking. In Sweden alone, near 9 million tons of standard coal biomass energy (gasified gases) was used as heating sources in 2003 [34]. Techniques with high heat value innoxious gasification and commercialization of gasified gases have being developed rapidly in China [52,53], for instance, the Energy Institute of Shandong Academy of Sciences has established the central gas supply system which has been widely spread in China's rural areas [54]. The shifting of energy source from firewood to crop residues gasification cannot only make the best utilization of rural energy, but also improve the ecological environment and farmers' living quality.

(2) *Crop residues electricity*: There are two kinds of approaches in generating electricity, direct burning or burning gases from crop residues, to drive the electricity-generating machines. Both techniques have been well developed, especially the former. The US leads the world in electricity-generating engines consuming crop residues, with nearly 400 biomass power plants. China achieved its first biomass electricity-generating project that used mixed crop residues and coal powder as fuels, in Shiliquan Power Plant of Shandong Province in December of 2005. If such a biomass power plant is run for 7500 h a year, some 107 thousand tons crop residues would be consumed, equaling to 58 thousand tons standard coal. Local farmers could make a profit of 30 million Yuan (about 3.8 million US dollar) from selling crop residues. Furthermore, some 1500 ton $SO_2$ could be reduced, meanwhile air pollution arose by noxious gases like CO and aerosols will be cut down [55].

(3) *Crop residues liquid fuel*: Nowadays biomass liquid fuel is a hot topic globally [56]. The Chinese government also paid much attention to developing biomass alcohol (particularly non-grain source). Since 1980s, breeding of the "sweet sorghum" has achieved great progress, with both the techniques of producing alcohol fuel and evaluation of the economic profits being upgraded year by year [57]. The scale of trial-produce was 5000 ton in 2001, since then, grain alcohol fuel projects (mostly from corn) have been taken into action to reduce the pressure of importing oils. For example, in 2005, China confirmed an alcohol fuel project in Jilin Province with the capacity of 600,000 ton per

year; afterwards the State Council approved a 200,000-ton project in Henan province, and another 100,000-ton project in Heilongjiang. There are approximately a hundred million tons overstocked grains in China, if they were all used to produce alcohol fuel, 32 million tons alcohol could be expected. However, corn stalks even produce more alcohol, since China has 240 million tons corn stalks per year, which could produce nearly 40 million tons alcohol only take 50% of the stalks into calculation. By doing so, we can save a great deal of corn grains.

### 4.3. Efficient returning crop residues to the soils could reduce environment pollution

Crop harvest and abandoned crop residues are factors intermitting the element cycling in farm ecosystems, so artificial fertilization is necessary to keep elemental balance. However, supply of a large amount of chemical fertilizers caused serious soil and underground water pollution, as only 40% of the applied fertilizers were absorbed by crops, with the rest leaching into the environment [32]. It is obvious that returning the large amounts of unused crop residues is the break point of agriculture in China. This can be restored by fertilizing fields with organic manures through livestock consuming the huge stalks resources. However, as the agricultural structure changed, farmers are no longer engaged in breeding big animals. This seriously separates the crop planting and livestock raising which leaves more crop residues as wastes. More seriously, it becomes worse as the Government cannot efficiently forbid direct burning crop residues in the fields [40]. Over commission of pesticide and herbicide, food pollutions are becoming increasingly severe as well [58,59]. Further more, irrational irrigations and soil erosions have challenged the soil elements balance in farmlands of China [60]. To solve the above-mentioned problems, uniform collection and treatment of surplus crop residues, plus animal digestion and returning back to the fields, must be the wisest way, which should be seriously considered.

### 4.4. Industrialization of crop residues has tremendous economic benefits

On one hand, the competition for food of human and livestock in China is extremely serious; on the other hand, a huge number of crop residues were burnt or wasted. It is theoretically practical to avoid such confliction, by industrializing crop residues into high quality forages. This can be a win–win situation of economic growth and environmental improvement in rural China, thus realizing the import goal of New Country Construction Motivation recently approved by the State Council [61]. Multiple advantages could be gained if crop residues industry were realized in China since animal breeding could extend food chain, greatly elevating energy transformation efficiency and ecological economic value. Since the manure is a good source for biomass energy, the remains could still be returned to the fields. To a larger scale, the national ecological balance could be realized if we shift the effort from grassland to farmland, utilizing the crop residues forage to feed animals like sheep and cattle rather than pigs who consumed a great deal of grains.

According to a brief calculation [50], the technique of transforming dry crop residues into "fresh bread" for livestock could bring up huge benefits. Firstly, to produce 85 million tons (only 13.5% of China's total crop residues yield) of such "bread forage" needs 106 million USD (about 850 million RMB) on the mechanism, about 550 million USD on microbial additive and packing plastic film. But the benefits are about 550 million USD for the coarse fodder processing, 700 million USD for the planting farmers, 740 million USD

for the raisers (compared with silage), and even the transporting trade could have about 310 million USD profits. The demand of animal coarse fodder in China is 2 billion tons every year, having a market potential over 75 billion USD. So, there is no doubt that enterprise with crop residues will be much more profitable than simply grain planting and harvest, which will be mostly suitable for the New Countries Construction Movement.

It is widely accepted that over-fertilizing would not helpful for increasing crop yield; and developing trans-genetic crops or high photosynthesis plants would not be environmental beneficent for a long time run. Since crop yield in China has reached a plateau, so the question remains, whether should we increase the grain yield with higher cost and gene-transfer risk, or shift our focus from chasing merely crop yield to comprehensive utilization of crop residues (e.g., to produce meet, milk, manure, energy, etc.)? The answer is obvious, since our solution will save 30% grains in China that are feed for pigs and chicken, and further more than 50% of the crop residues which have not been fully exploited. Starting with adjustment of utilization structure of crop residues resources, we believe industrialization of crop residues forage is a breakthrough point.

As a conclusion, China has enormous crop residues distribution, which is equally important with grains from the resource and energy points of view. However, such enormous resources need highly efficient and recycling utilization, which is crucial for releasing future food crisis, improving natural and social conditions and providing bioenergy and increasing farmers' income. Among all the complicated suggestions, the ecological comprehensive utilization of crop residues, particularly the industrialization of coarse forage should be firstly considered.

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